Accelerated Bridge Program

10 Bridges and Roadway Projects

Risk Analysis & Sequencing Report
Update 1

November 10, 2010

DRAFT

(Modified version includes summaries and Longfellow results only as requested by Amy Getchell on 6/14/2011)

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Moving Massachusetts Forward. massDOT Highway

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Executive Summary

This report provides an update to the June 2010 ABP Risk Analysis and Sequencing Report Update 1, submitted by the PARMS team. This work is part of our work on MassDOT Contract No. 60273 titled Active Risk Management and Sequencing. As part of the risk management process, regular updates to the analysis take place, as designs, project costs, schedules and risks are continually refined throughout the project life cycle. This report serves as the first update to the June 2010 ABP Risk Analysis and Sequencing Report. A 2-day risk workshop was held on September 21 and 22, 2010, to update key assumptions on base cost and schedule, as well as key cost and schedule risks for four Massachusetts Department of Transportation (Mass DOT) Accelerated Bridge Program (ABP) projects:

- Longfellow Bridge Phase 2;
- Anderson Memorial Bridge;
- River Street Bridge; and
- Western Avenue Bridge.

Additionally the base cost and schedule assumptions have been updated for several of the other projects in the report to reflect the most current information, available in the September 2010 MassDOT ABP Quarterly Report.

A key update to the sequencing of projects was to constrain the River Street and the Western Avenue Bridges to occur in parallel, and not allow Anderson Memorial Bridge to overlap with River and Western. Two scenarios have been tested to examine optimal sequencing:

- Scenario 1 – The River Street and Western Avenue Bridges are constructed first and the Anderson Memorial Bridge starts after the River Bridge and Western Avenue Bridge Construction are complete; and
- Scenario 2- The Anderson Memorial Bridge is constructed first and the River Street Bridge and the Western Avenue Bridge starts after the Anderson Memorial Bridge construction is complete.

Scenario 1 was found to have the optimal sequencing. In terms of total construction and traffic costs, it is optimal to have the Anderson Memorial Bridge construction start up after the River Street Bridge and Western Avenue Bridge are complete.

Table ES-11 presents the results for Scenario 1, which was determined to be the optimal sequence from information available at this time and data used in the analyses.

Table ES-11: Sequencing Results Summary – Scenario 1

Cost Categories	Baseline Sequence – Pre-Risk Response	Optimized Sequence - Pre-Risk Response	Change over Baseline (Cost Avoidance)	Optimized Sequence - Post-Risk Response	Change over Baseline (Cost Avoidance)
Total Cost (All Bridges)	**$682.1**	**$681.1**	**-$1.0**	**$671.6**	**-$10.5**
Non-Escalated Cost	$536.2	$536.2	$0.0	$530.0	-$6.2
Cost of Escalation	$134.5	$135.5	$1.0	$132.1	-$2.5
Project Overlap Costs	$11.3	$9.4	-$2.0	$9.5	-$1.8
Traffic Disruption Costs	**$143.9**	**$140.3**	**-$3.6**	**$137.1**	**-$6.7**
Total Costs (Traffic and Construction)	**$826.0**	**$821.4**	**-$4.6**	**$808.7**	**-$17.2**

Overall the sequencing optimization reduces project costs by $1.0 million in the pre- risk mitigation results and $10.5 million in the post-risk mitigation results. This is due to savings in project overlap and a reduction of escalation costs. Additionally, there is a savings of $3.6 million in pre-mitigation and $6.7 million in post-risk mitigation for traffic disruption costs due to the optimized sequence.

When re-sequencing the work to put the Anderson Memorial Bridge ahead of the River Street and Western Avenue Bridges, there is an additional cost of $9.9 million related to project overlaps and traffic disruption costs for the pre-risk mitigation results. This number increases to $11.4 million in the post-response. Section 3.4 provides the detailed information.

VHB has prepared a review of the Phase I study dated August 2008 and completed by the BETA Group, et. al, entitled "Existing Origin-Destination Review and Construction Sequencing Evaluation." Their report is included in Appendix D. The results of this document are used to estimate the costs of traffic delays for inclusion in the risk assessments.

Initial Risk Assessment and project optimization have been conducted on ten bridge projects. Of these projects, four have gone through the risk mitigation planning to address the risks. This leaves significant work to still be done on the assessment of risks to the ABP, including periodic reassessments at the project designs develop through 50 and 90% levels as well as through construction.

The next steps are to conduct risk response workshops for the Craigie Drawbridge, BU Bridge, Magazine Beach Pedestrian Bridge, Massachusetts Turnpike Viaduct, Longfellow Bridge Phase 2, and the Craigie Roadway to further define and refine the risks. These new results will be added to this report for further understanding of cost and schedule risks and their impacts on the program sequencing. Following that, additional projects should be identified for risk analysis workshops and inclusion into the sequencing models. The sequencing model can then be updated based on the new inputs. Throughout these next steps, the ongoing work on each bridge will be tracked and so that the cost risk analysis and sequencing model are continuously refined.

The work to date shows a significant addition to expected cost from escalation. This result contradicts the observed condition over the past two years that construction prices are in fact contracting, not escalating. This contradiction is being further evaluated and the results will be included in the next round of assessments.

Base prices are considerably higher than current market conditions indicate based on contracts awarded nationwide over the past 1-2 years. This outcome results from the way unit costs are given in the MassDOT procedures used to develop the Engineer's cost estimate. The impact of this difference will be included in the next round of assessments by examining unit costs and schedule from a contractor's perspective.

Summary of Work Performed and Results

This provides an update to the June 2010 ABP Risk Analysis and Sequencing Report. As part of the risk management process, regular updates to the analysis take place, as project costs, schedules and risks are continually refined throughout the project life cycle. This report serves as an update to the June 2010 ABP Risk Analysis and Sequencing Report. A 2-day risk workshop was held on September 21 and 22, 2010, to update key assumptions on base cost and schedule, as well as key cost and schedule risks for four Massachusetts Department of Transportation (Mass DOT) Accelerated Bridge Program (ABP) projects:

- Longfellow Bridge Phase 2;
- Anderson Memorial Bridge;
- River Street Bridge; and
- Western Avenue Bridge.

Additionally the base cost and schedule assumptions have been updated for several of the other projects in the report to reflect the most current information, available in the September 2010 MassDOT ABP Quarterly Report, not including the Massachusetts Turnpike Viaduct project which is not a MassDOT project and the Craigie Roadway project (not including the Craigie Drawbridge project work). Table ES1 summarizes the changes in cost and schedule inputs between the June and September 2010 analyses.

Table ES1: Updated Project Cost and Schedule and Schedule Inputs

Bridge Name	Cost ($ million)			Notice to Proceed Date		
	Previously Reported (June 2010)	Sept 2010 Update	Difference ($ million)	Previously Reported (June 2010)	Sept 2010 Update	Difference (months)
Longfellow Bridge Phase 1	$42.80	$18.00	-$24.80	Sep-2010	Jun-2010	-3.0
Anderson Memorial Bridge	$18.00	$28.40	$10.40	Aug-2011	Jul-2011	-1.0
Western Avenue Bridge	$21.00	$24.20	$3.20	Aug-2011	Sep-2011	1.0
River Street Bridge	$21.00	$24.20	$3.20	Aug-2011	Sep-2011	1.0
Craigie Drawbridge**	$34.00	$36.50	$2.50	Nov-2010	Nov-2010	0.0
BU Bridge*	$20.00	$16.20	-$3.80	Jun-2009	Jun-2009	0.0
Magazine Beach Pedestrian Bridge	$3.60	$3.80	$0.20	Mar-2010	Apr-2010	1.0
Mass Turnpike Viaduct***	$8.00	n/a	n/a	Mar-2014	n/a	n/a
Longfellow Bridge Phase 2	$255.60	$255.60	$0.00	Jan-2012	Aug-2012	7.0
Craigie Roadway**	$5.00	n/a	n/a	Feb-2010	n/a	n/a

*Note: September 2010 Update based on September 2010 MassDOT ABP Quarterly Report. * For BU Bridge, the totals do not include the $3.4 million of sidewalk replacement cost, which was essentially completed in summer of 2009. ** Craigie projects are bundled as one- Dam Bridge Rehab #604685, kept separate in risk analysis and sequencing, no change to the roadway inputs in this analysis .Roadway project cost was kept constant at $5.0 million and backed out of the total cost reported for project #604685 to get the total for the Drawbridge project. *** Not a MassDOT project- inputs provided during April 8, 2010 workshop*

The September 2010 update workshop also facilitated some general discussions pertaining to updates to the Accelerated Bridge Program. The Interstate 93 (I-93) Bridge reconstruction project will be added to the ABP, although it is yet to be incorporated in the risk and project sequencing analyses. In terms of project costs for the ABP, for current projects that have been bid, the bids are about 28 percent less than engineers' estimates. Given the divergence between recent bids and the engineers' estimate, the program may expect change orders resulting in additional costs as well as delays in construction of up to three months. Accordingly construction baseline schedules for some projects have changed and are accounted for in the cost risk analysis and sequencing model, based on the ABP Project Summary Schedule Report – September 2010.

During a top level review of the risk assessment results, questions were raised about using baseline cost and schedule estimates without including uncertainty in these items, basis for the escalation rate and basis for the interest rate. Market conditions are much different now than those given in the latest version of the Massachusetts state database. The following actions are being taken to address these concerns:

- The baseline cost and schedule estimates will be reviewed by the team to include uncertainty in unit price, quantities and schedule components;
- The escalation rate will be updated to incorporate current trends in market pricing and projected trends over the next 5 years; and
- The inflation rate will be updated to incorporate current estimates on inflation rate for the next 5 years.

More details regarding the discussions regarding these four bridges held during the workshops are summarized below.

Longfellow Bridge Phase 2 Updates

The second phase of construction on Longfellow Bridge cannot begin until Phase 1 (currently underway) is completed. Although there have been no significant changes during Phase 1, is the schedule is two to three weeks behind in construction production rates and shop drawings submittals are also behind schedule. At this time, the Phase 2 schedule has been delayed for four months from the previous assessment, with construction starting in April 2012. With input from the Longfellow Task Force, the Longfellow Environmental Assessment (EA) filing has been delayed to further investigate all the design alternatives. The EA is scheduled to be filed sometime in the next few months. This EA filing date shows a delay from our previous date in November 2010. Ongoing tracking and monitoring of the progress of Phase 1 will be important to our assessment to include their effects on the risk management work.

MassDOT Longfellow Bridge Task Force Committee: In June of 2010, MassDOT convened the Longfellow Bridge Rehabilitation Task Force Committee. This Task Force Committee met 9 times between June 2010 and October 2010. Several key issues were discussed during the workshop in relation to the Task Force that may impact the Longfellow Bridge Phase 2 Project. First, the Task Force findings may prompt MassDOT to add additional intersections for improvements, especially at Charles

Circle, which will pose additional traffic risks. Second, an additional pedestrian bridge proposed by the Task Force would add $8-$10 million to the project cost and also add additional time to the schedule (Note: that the proposed Pedestrian Bridge is presently only in a conceptual design phase). The ABP team is expecting that there may be other potential changes to the current scope from other future task force groups.

Massachusetts Bay Transit Authority (MBTA): During the workshop, the PARMs team learned that the Shoofly/MBTA reservation rehabilitation portion of the project will likely occur. With the Shoofly MBTA reservation rehabilitation work moving forward, additional bussing costs and traffic impacts have been considered by the PARMs team.

Other issues discussed during the workshop that may bring about delays to the project include design issues which may delay the final NTP, concerns over the conditions of the timber piles and seismic shear ties to piers, the traffic risk of losing the westbound closure during construction, impacts of not moving a historical wall located on DCR Park land, and the condition of the arches.

Anderson Memorial Bridge Updates

A key update to this project's baseline schedule taken from the September workshop is that the Anderson Memorial Bridge is assumed to start after River and Western Bridges are completed (as a baseline input to the sequencing model; however the sequencing model also allows and tests Anderson starting after River and Western). In the sequencing model, two scenarios are tested based on the constraints that construction of the Anderson Memorial Bridge does not overlap River and Western Bridge construction. Based on current expectations, the project should not conflict with Longfellow Bridge project from a risk management perspective. Based on the September workshop, it was noted that there are updates to the Traffic Management Plan (TMP) during design and construction that could have schedule impacts. These impacts have been added as an external risk, but have not yet been quantified.

Several other key components of the risk profile have been updated during the September workshop. Previous traffic related issues regarding the pedestrian/bike underpass are no longer options being considered, which has reduced project risk. In terms of utility risks, coordination is still ongoing with the Massachusetts Bay Transit Authority (MBTA) and various utility companies in Boston and Cambridge. In particular, Verizon is scheduled to move ducts during construction, the MWRA will need to install valves on their water main for future shutdowns. A risk mitigation options discussed in the workshops was to develop pre-construction contracts to complete utility work for communications, water and sewer before the main contract begins to reduce their potential effects on the main construction contract and thereby reduce risk.

Currently there have been no changes in the observed condition of the arches since the previous reporting. The project does not have any historic permitting issues, as all work being performed is considered repair or rehabilitation. There is a possibility that some structures may need to be

reinforced. This work could add six to eight weeks to the design and construction schedule. All old brick work with architectural details will need to be replaced.

In terms of environmental risk, the project may require a National Environmental Policy Act (NEPA) permit for cutting down trees if the quantity exceeds five (presently four have been identified). Mitigation measures for this unknown are being considered. Also during the workshop the project team discussed the Marine Fisheries Time of Year (TOY) Restrictions, which include a time period in the spring and fall (dates depend on the species of fish in question) for which barges- they can be in river, but need to remain stationary. It appears these risks would impose potential schedule delays prior to construction, impact construction duration as well as influence sequencing of work within the project. These risks have been discussed but not yet quantified.

River Street Bridge Updates

New updates and discussions on the River Street Bridge are similar to those on the Western Avenue Bridge project. Key items discussed during the workshops include additional study on the condition of the retaining/sea walls connected to the River Street Bridge. The wall is under DCR management but is not part of the ABP bridge rehabilitation work for the River Street Bridge. There is a credible possibility that the wall will need repair work to safely complete the bridge work. Although similar in scope to the Western Avenue Bridge project, the River Street project could have more severe impacts to schedule with cost due to constructability issues. In particular, loading and unloading issues during construction may be a more of an issue at the River Street Bridge. Utilities will not be disturbed, but will be temporarily relocated for the rehabilitation work. It is important to note that work on a gas line must be completed in the summer months as it supplies the North Shore and Cambridge. Workshop updates to traffic risks will require a revised TMP for River, Western, and Anderson projects.

Western Avenue Bridge Updates

There are similar issues regarding the conditions of the retaining/ sea walls connected to the Western Avenue Bridge as discussed previously. Limited equipment access to site may add a premium to construction costs. Other updates to this project include MassDOT coordination with the City of Cambridge for their Western Avenue Sewer Reconstruction project that could coincide with the rehabilitation work on this bridge. A recent unrelated lane closure led to severe traffic backups and this might be used as a lesson learned for traffic management plans. Possible structural issues regarding arches and potential issues with the usable life of bridge after the rehabilitation project were discussed but not yet quantified.

Updated Risk Analysis Results

Based on the updates on all ABP projects reported in **Table ES1** and on the risk profiles for the Longfellow Bridge Phase 2, Anderson Memorial, River Street and Western Avenue bridges cost and schedule risk analyses have been performed and the results are provided in the following tables. In terms of project cost, the median estimate of the ten ABP project is projected to reach $647.7 million. Compared to the last update in Spring of 2010, this is an increase of $43.3 million which is mainly due to

the updated cost, schedule, and risk profile for the Longfellow Bridge Phase 2. Additionally, work on the Longfellow Bridge Phase 2 is expected to be completed two years later than the spring 2010 update. However the overall difference in project completion date is only 0.3 months as work on Western Avenue Bridge and River Street Bridge is projected to be completed sooner than expected in the spring 2010 analysis. The cost and completion date of each project is reported in **Table ES 2**.

Table ES 2: Preliminary Program Results –Total Project Cost in Millions (2010 $), 50th percentile

Bridge Name	Risk Adjusted Total Project Cost in Millions (2010 $)			Risk-Adjusted Project Completion Date		
	Previously Reported (June 2010)	Sept 2010 Update	Difference ($ million)	Previously Reported (June 2010)	Sept 2010 Update	Difference (in months)
Longfellow Bridge Phase 1	$51.52	$24.03	-$27.49	May-12	Mar-12	-1.6
Anderson Memorial Bridge	$25.84	$33.67	$7.83	Nov-13	Jul-13	-3.8
Western Avenue Bridge	$30.16	$35.04	$4.88	Apr-15	Mar-14	-12.6
River Street Bridge	$39.87	$45.92	$6.05	Jan-16	Feb-15	-10.2
Craigie Drawbridge	$41.10	$41.86	$0.76	Apr-11	Aug-11	4.0
BU Bridge	$20.39	$16.54	-$3.85	Jan-12	Jan-12	0.4
Magazine Beach Pedestrian Bridge	$3.98	$4.14	$0.16	Sep-11	Oct-11	1.0
Mass Turnpike Viaduct	$11.11	$11.11	$0.00	Apr-16	Apr-16	0.9
Longfellow Bridge Phase 2	$375.43	$430.41	$54.98	Dec-17	Sep-19	21.6
Craigie Roadway	$5.00	$5.00	$0.00	Aug-11	Aug-11	0.5
Total	**$604.40**	**$647.73**	**$43.33**	-	-	**0.3**

Note: Cost and schedule results are presented at the 50th percentile and include risk response strategies for projects where risk response strategies have been identified and quantified. Cost and schedule difference columns measure the September 2010 minus the June 2010 results. Therefore a positive number indicates an increase in cost or a later completion date, whereas a negative number indicates a reduction in cost or an earlier end date. For example for Longfellow Bridge Phase 1, negative 1.6 months indicates in the updated analysis the project is anticipated to be completed 1.6 months earlier than in the previous analysis. Reasons for this difference in schedule dates can be due to both changes in the quantified schedule risks as well as changes in the baseline schedule dates.

Updated Optimal Sequencing Results

A key update to the sequencing of projects was to constrain the River Street and the Western Avenue Bridges to occur in parallel, and not allow Anderson Memorial Bridge to overlap with River and Western. Two scenarios have been tested to examine optimal sequencing:

- Scenario 1 – The River Street and Western Avenue Bridges are constructed first and the Anderson Memorial Bridge starts after the River Bridge and Western Avenue Bridge Construction are complete; and
- Scenario 2 – The Anderson Memorial Bridge is constructed first and the River Street Bridge and the Western Avenue Bridge starts after the Anderson Memorial Bridge construction is complete.

Scenario 1 was found to be the optimal sequencing. In terms of total construction and traffic costs, it is optimal to have the Anderson Memorial Bridge construction start up after the River Street Bridge and Western Avenue Bridge are complete. The difference in pre- and post- risk response cases are reported in **Table ES 3** and **Table ES 4** respectively. As summarized in the table, the total construction cost is about $2.5 million less expensive in the optimum, pre- or post-risk response (Scenario 1). In both Scenarios 1 and 2 there is some escalation cost savings (average of about $1.7 million) by having the Anderson Memorial Bridge work to go first, but these savings are outweighed by the additional project overlap costs. When accounting for traffic disruption costs, an additional $10 to $11 million will be spent to have the Anderson Memorial Bridge proceed ahead of the River Street and the Western Avenue Bridges (Scenario 2).

Table ES 3: Sequencing Model Scenario Comparison – Pre-Risk Response Costs in Millions (2010 $)

Cost Categories	Optimized Sequence - Pre-Risk Response		Difference
	Scenario 1 - River and Western First	Scenario 2 - Anderson First	
Total Cost (All Bridges)	**$681.10**	**$683.52**	**$2.43**
Non-Escalated Cost	$536.21	$536.21	$0.00
Cost of Escalation	$135.52	$133.74	($1.78)
Project Overlap Costs	$9.36	$13.57	$4.21
Traffic Disruption Costs	**$140.29**	**$147.81**	**$7.52**
Total Costs (Traffic and Construction)	**$821.38**	**$831.33**	**$9.95**

Table ES 4: Sequencing Model Scenario Comparison – Post-Risk Response Costs in Millions (2010 $)

Cost Categories	Optimized Sequence - Post-Risk Response		Difference
	Scenario 1 - River and Western First	Scenario 2 - Anderson First	
Total Cost (All Bridges)	**$671.57**	**$674.10**	**$2.53**
Non-Escalated Cost	$530.03	$530.03	$0.00
Cost of Escalation	$132.05	$130.51	($1.54)
Project Overlap Costs	$9.49	$13.56	$4.07
Traffic Disruption Costs	**$137.13**	**$146.00**	**$8.86**
Total Costs (Traffic and Construction)	**$808.71**	**$820.09**	**$11.39**

Table ES 5 reports the pre-risk response baseline total cost and the optimized sequencing results for the ten ABP projects. Optimality shows that the work on the Anderson Memorial Bridge should begin after the River Street and Western Avenue bridges (Scenario 1) to minimize escalation and project overlap costs. When the sequencing of the schedule is reversed so that construction on the Anderson Memorial Bridge is completed prior to beginning the River Street and Western Avenue Bridge construction

(Scenario 2), the non-optimized outcome results in higher overall costs of around $2.5 million as shown in **Table ES 4**.

Table ES 5: Optimal Sequencing Results (Without Traffic Disruption Costs)

Bridge Name	Baseline Total Cost	Optimization Total Cost - Pre-Risk Response	Change over Baseline Pre-Risk Response	Optimization Total Cost - Post-Risk Response	Change over Baseline Post-Risk Response
Longfellow Bridge Phase 1	$25.7	$25.7	$0.0	$27.2	$1.4
Anderson Memorial Bridge	$43.9	$41.9	-$2.0	$39.3	-$4.6
Western Avenue Bridge	$41.9	$41.9	$0.0	$35.9	-$6.0
River Street Bridge	$48.8	$48.8	$0.0	$48.1	-$0.7
Craigie Drawbridge	$46.6	$46.6	$0.0	$46.6	$0.0
BU Bridge	$16.8	$16.8	$0.0	$16.8	$0.0
Magazine Beach Pedestrian Bridge	$4.5	$4.5	$0.0	$4.4	$0.0
Mass Turnpike Viaduct	$11.7	$12.7	$1.0	$12.7	$1.0
Longfellow Bridge Phase 2	$437.0	$437.0	$0.0	$435.4	-$1.6
Craigie Roadway	$5.2	$5.2	$0.0	$5.2	$0.0
Total	**$682.1**	**$681.1**	**-$1.0**	**$671.6**	**-$10.5**

Note: Costs are based on the 50th percentile risk analysis results as an input to the sequencing model, and include escalation costs and project overlap cost premiums due to labor and material shortages.

In project sequence optimization, the project with the most significant increase in total cost due to the optimization of sequencing is the Longfellow Bridge Phase 1 due to project overlap costs, as it's the fourth consecutive project to overlap (see Appendix B2 for information on sequencing assumptions), with the post-risk response cost estimate reaching $27.2 million. This increase in cost is due to the estimated cost of the risk response strategy exceeding the cost savings from implementing it, rather than costs associated with the sequencing. Given this result, the recommendation from this report is to not pursue the risk response strategy for the project, without further revisiting the costs and benefits associated with it. Anderson Memorial Bridge, Western Avenue Bridge, and River Street Bridge will experience decreases in cost as a result of the scheduling optimization. Total cost estimates (post-risk response) for the three projects are $39.3 million, $35.9 million, and $48.1 million respectively. These three cost estimates reflect total cost avoidance of $11.3 million, due to reductions in overlapping cost premiums and escalation cost savings. These numbers are considerably affected by the estimated escalation costs.

The comparison of the baseline estimate to the optimized estimate of total ABP project costs results in $4.6 million in terms of cost avoidance from project optimization for the pre-risk response results. With risk-mitigation, the amount of cost avoidance from the baseline estimate is $17.2 million. The cost avoidance comes in several forms, base cost reductions due to risk response strategies, escalation cost avoidance, project overlap cost avoidance and traffic disruption cost avoidance. The breakdown of total cost in terms of non-escalated cost, escalated cost, and project overlap cost is reported in **Table ES 6**.

The optimization results reported are risk-adjusted (from baseline cost uncertainty) and escalated; but there are very few changes between optimized and non-optimized due to new scheduling constraints in the sequencing model.

Table ES 6: Sequencing Summary Results- Costs by Category

Cost Categories	Baseline Sequence – Pre-Risk Response	Optimized Sequence - Pre-Risk Response	Change over Baseline (Cost Avoidance)	Optimized Sequence - Post-Risk Response	Change over Baseline (Cost Avoidance)
Total Cost (All Bridges)	**$682.1**	**$681.1**	**-$1.0**	**$671.6**	**-$10.5**
Non-Escalated Cost	$536.2	$536.2	$0.0	$530.0	-$6.2
Cost of Escalation	$134.5	$135.5	$1.0	$132.1	-$2.5
Project Overlap Costs	$11.3	$9.4	-$2.0	$9.5	-$1.8
Traffic Disruption Costs	**$143.9**	**$140.3**	**-$3.6**	**$137.1**	**-$6.7**
Total Costs (Traffic and Construction)	**$826.0**	**$821.4**	**-$4.6**	**$808.7**	**-$17.2**

As discussed earlier, construction on the Western Avenue and River Street Bridges is constrained to move together while that on the Anderson Memorial Bridge is constrained by traffic needs to proceed strictly before or after that of River and Western Bridges. Optimality requires that the Massachusetts Turnpike Viaduct to be delayed for two years. Combined with risk-response strategies, the construction on the Anderson Memorial Bridge and Western Avenue Bridge will be significantly shorter. The schedule results from the optimal sequencing are shown in **Table ES 7.**

Table ES 7: Sequencing Summary Results- Schedule

Cost Categories	Project Baseline Sequence - Pre-Risk Response		Optimized Sequence - Pre-Risk Response		Optimized Sequence - Post-Risk Response	
	Construction Duration (months)	End Date	Construction Duration (months)	End Date	Construction Duration (months)	End Date
Longfellow Bridge Phase 1	23.9	Jul-2012	23.9	Jul-2012	24.3	Jul-2012
Anderson Memorial Bridge	23.9	Apr-2017	23.9	Apr-2017	21.0	Dec-2016
Western Avenue Bridge	33.8	Nov-2014	33.8	Nov-2014	36.5	Jan-2015
River Street Bridge	37.8	Apr-2015	37.8	Apr-2015	38.6	Mar-2015
Craigie Drawbridge	5.5	Apr-2011	5.5	Apr-2011	5.5	Apr-2011
BU Bridge	29.3	Dec-2011	29.3	Dec-2011	29.3	Dec-2011
Magazine Beach Pedestrian Bridge	17.9	Sep-2011	17.9	Sep-2011	16.9	Aug-2011
Mass Turnpike Viaduct	23.0	Feb-2016	23.0	Jan-2018	23.0	Jan-2018
Longfellow Bridge Phase 2	72.8	Apr-2019	72.8	Apr-2019	70.7	Feb-2019
Craigie Roadway	17.5	Aug-2011	17.5	Aug-2011	17.5	Aug-2011

In summary, in terms of project cost, following the update, the overall costs for the 10 bridges at the 50th percentile is approximately $40 million higher than the previous reporting. While some projects have decreased in cost, most significantly Longfellow Phase 1 which was updated to reflect the current

bid cost, several other projects have increased in costs. Most significantly is Longfellow Phase 2, which shows an increase from the previous reporting of nearly $55 million. This is entirely driven by updates the project's risk profile. Currently the two largest risks to the project are a traffic risk that the westbound detour won't happen and a construction risk addressing cost overrun, due to the MBTA Shoofly being constructed on the unimproved side of bridge. Full details on the risks to this project are provided in Section 2.9.1.

Similarly with schedule, the largest positive change in completion dates is Longfellow Bridge Phase 2, which is not estimated to be completed nearly 22 months later than in the previous assessment. A key driver of this later completion date is the delay in NTP for final design at the time of the September 2010 workshop. Beyond that, the largest single schedule risk for the project is that the westbound detour will not occur, which adds an additional 12 to 18 months of construction duration. During the update workshop, the probability of this risk was increased from 10 percent to 50 percent, given the current likelihood of not having the westbound detour. Both Western Avenue and River Street Bridges show significantly earlier end, both finishing in excess of 10 months earlier than in the previous reporting. While the changes in the baseline schedule are minor for both projects. This is driven by a reduction in schedule risks, as the changes to the baseline schedules for both projects were relatively minor.

The key updates from the updates to the optimal sequencing are the two scenarios that were developed to be tested. Scenario 1 examines the sequencing impacts of constructing River Street and Western Avenue Bridges prior to starting construction on Anderson Memorial Bridge and Scenario 2 examines the opposite, constructing Anderson Memorial Bridge first. The decision was made in the September 2010 update workshop to not allow the construction of these two bridges to overlap for any substantial duration. The results of the updated optimal sequencing analysis show that Scenario 1, constructing River Street and Western Avenue bridges first is the optimal sequence.

1 Overview

The Partners for Active Risk Management (PARM) team has been contracted by MassDOT to perform cost and schedule risk analysis and optimal sequencing modeling for the Accelerated Bridge Program (ABP). To date, the PARM team has evaluated ten projects. The risk analysis and optimal sequencing is a continual process, which is scheduled to be updated on a regular basis. Table 2 presents a list of these ten projects and details the dates of all assessment workshops and when the most recent informational updates occurred.

The risk profiles for four of the projects were recently updated in the September 21 and 22, 2010 workshop. Additionally there were some updates to the baseline schedules for some additional projects; however these updates are not reflected in the table as it only summarizes the changes in the risk profiles. To date, four of the projects have also gone through risk response workshops, where mitigation strategies to reduce the likelihood and impacts of key risk factors were identified. The focus of the September 2010 workshop was to update the current quantification of the risks including definition of additional risk elements not previously identified. Risk response strategies were not a focus of the discussions for the September workshop.

Table 2: Project Risk Assessment List

Count	Project Name	Initial Risk Assessment	Last Update of Risk Assessment	Risk Response Session
1	Longfellow Bridge Phase 1	November 12, 2009	April 15, 2010	April 15, 2010
2	Anderson Memorial Bridge	March 16, 2010	September 22, 2010	April 15, 2010
3	Western Avenue Bridge	March 16, 2010	September 22, 2010	April 15, 2010
4	River Street Bridge	March 16, 2010	September 22, 2010	April 15, 2010
5	Craigie Drawbridge	March 30, 2010	-	To be scheduled
6	BU Bridge	March 30, 2010	-	To be scheduled
7	Magazine Beach Pedestrian	April 8, 2010	-	To be scheduled
8	Mass Turnpike Viaduct	April 8, 2010	-	To be scheduled
9	Longfellow Bridge Phase 2	April 8, 2010	September 22, 2010	To be scheduled
10	Craigie Roadway	April 8, 2010	-	To be scheduled
…	Additional Projects to be Added	To be determined		

The objectives of the risk assessments are to:

- Identify and quantify key project risk factors within a consensus based workshop;
- Assess the uncertainty in the base cost estimates;
- Produce probabilistic cost and schedule estimates using numerical integration of individual risk elements; and
- Identify actions that can be taken to reduce the impact of risk factors and quantify their impacts on project cost and schedule (risk response).

To achieve these objectives, several risk workshops were conducted, with participants from MassDOT, project designers and the PARM team. During each workshop the cost and schedule estimates for the project were assessed in a consensus-based manner. Panelists in the workshop were asked to opine on the likelihood and impacts (in terms of costs and delay) of potential project risks in their areas of expertise. These risk inputs feed into the analysis to determine overall project cost and schedule durations, represented by probability distributions. Risk Response sessions give panelists an opportunity to review the project risks and address options to reduce the cost and schedule impacts through mitigation.

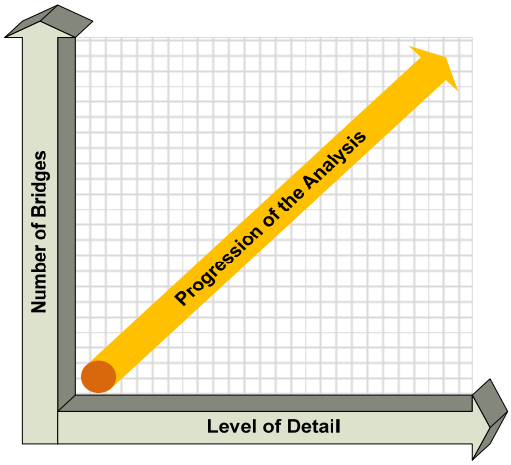


Figure 1: Scalability of the Analysis

The second step of the analysis examined the sequencing of projects, taking into account potential cost premiums for overlapping projects (potentially due to limited number of contractors, labor force or material shortages), overall project costs and traffic disruption impacts. The impacts of the baseline sequence were calculated and a sequencing model was used to solve for the optimized project sequencing for the ten projects currently in the analysis. The optimal sequencing is calculated for both the initial risk analysis results and those accounting for the risk response strategies. This analysis is scalable and the intention is to refine it over time, by adding additional bridge projects as well as examining each project in further detail. This concept is illustrated in Figure 1. The results presented in this memorandum represent a working draft which will continue to be refined in the future.

The remainder of this memorandum is structured as follows. Chapter 2 presents the results of the risk analysis for each of the 10 projects. For projects where a risk response workshop was conducted, results with risk response strategies are presented as well. Chapter 3 presents the results of the sequencing analysis for both the initial risk analysis and risk response results. Chapter 4 presents conclusions of the overall analysis.

In addition to this document, a separate appendix document provides background information and data sets used in the analysis. Appendix A provides an overview of the risk analysis methodology, including the cost and schedule risk analysis and risk response planning. Appendix B presents the inputs used in the development of this report, while Appendix C presents risk worksheets that describe the quantification for each risk item, by project.

2 Cost and Schedule Risk Analysis Results

This chapter presents the cost and schedule risk analysis results for each of the 10 projects. Table 3 provides an indication of which sections in Chapter 2 have been updated since the last report, given changes to the inputs. These sections present the updated results, if applicable, from the September 2010 update. For a comparison between the updated results and the previous report, see Table ES 2 in the report summary.

Table 3: Risk Key –Project Update Indicator

Count	Project Name	Updated in this Report? (Which Inputs Have Changed)
1	Longfellow Bridge Phase 1	✓ (Updated base cost and schedule)
2	Anderson Memorial Bridge	✓ (Updated base cost, schedule and risks)
3	Western Avenue Bridge	✓ (Updated base cost, schedule and risks)
4	River Street Bridge	✓ (Updated base cost, schedule and risks)
5	Craigie Drawbridge	✓ (Updated base cost)
6	BU Bridge	✓ (Updated base cost)
7	Magazine Beach Pedestrian Bridge	✓ (Updated base cost and schedule)
8	Mass Turnpike Viaduct	(no change)
9	Longfellow Bridge Phase 2	✓ (Updated base cost, schedule and risks)
10	Craigie Roadway	(no change)

2.1 Longfellow Bridge Early Action (Phase I)

This section contains the results of the cost and schedule risk analysis for the Longfellow Bridge Early Action (Phase I) Project. While the risks were not updated in the September 2010 workshops, the base cost estimate and schedule estimates have been updated to reflect the values from September 2010 Accelerated Bridge Program quarterly report. The results include key cost and schedule event risks as defined by the panelists during the November 12, 2009 workshop; the probability distribution of total project cost; and the probability distribution of project completion under the baseline (non-optimized) scenario. Both the initial and risk response results are presented for this project. Since the time of the analysis, this project has been bid, and the current base cost and schedule reflect those from the bid, as provided in the latest ABP Quarterly Report. Since the risk quantification has not been revisited since it was initially examined in November 2009, the results presented in this report reflect the original risk profile, prior to bid. The next steps for this assessment include convening a workshop in the near future to update the assessment for Longfellow Bridge Phase 1 among other projects.

2.1.1 Key Project Risk Factors

Key project risk factors are potential events that will impact the cost or schedule of the Longfellow Bridge Project Phase 1. These events are characterized by a probability of occurrence and potential range of impact if they occur. Figure 2 illustrates the top cost and schedule impacts of risk events while Figure 3 illustrates the critical path schedule risk impacts at their expected value. Table 4 provides the full risk name for each risk listed in Figure 2. In each chart, both the initial and the risk response results are shown for the top ten risks. The risk response results represent the impact of risk response strategies, such as mitigation, discussed during the risk response workshop.

Table 4: Risk Key - Longfellow Bridge Early Action (Phase 1)

Rank	Risk ID & Name
1	CON 14 - Construction Risk – Noise
2	UTL 2 - Utilities Risk - Verizon Cutovers
3	UTL 1 - Utilities Risk - Level 3 Cutovers
4	CON 18 - Construction Risk - Masonry in the Splash Zone
5	TRA 3 - Traffic Risk - Closure of 2 Lanes
6	CON 19 - Construction Risk - Debris at Base of Piers
7	CON 6 - Construction Risk - MBTA Actions
8	ENV 2 - Environmental Risk - Conservation Commission Requirements
9	CON 1 - Construction Risk – Mobilization
10	EXT 1 - External Risk - Weather Delays

Figure 2: Combined Cost and Schedule Tornado Chart – Longfellow Bridge Early Action (Phase 1)

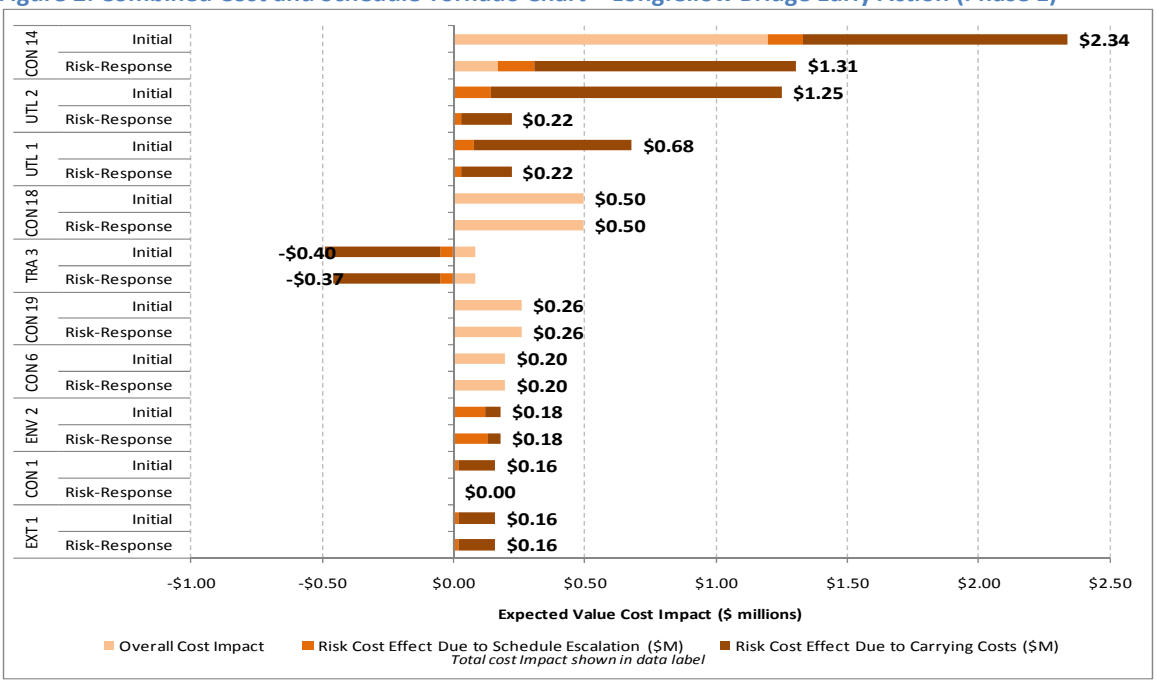
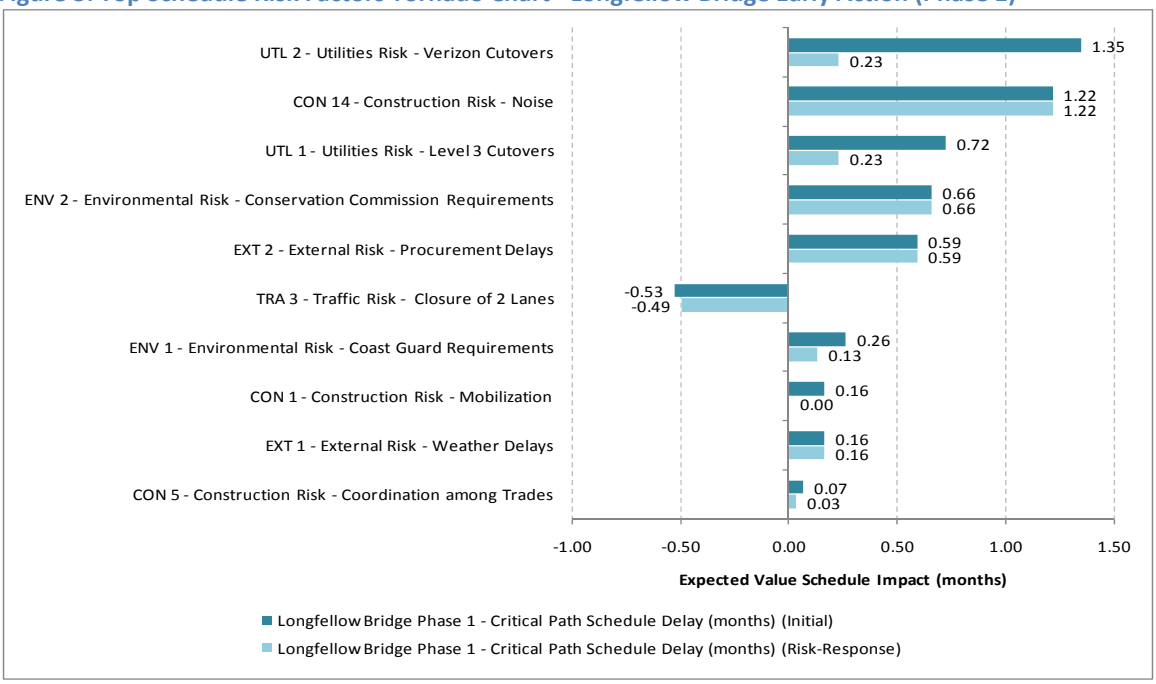


Figure 2 shows the expected value cost impact of each individual event risk. The overall cost impact is composed of three parts: an event risk cost component, the escalation cost effect if the risk contributes to a delay, and the cost overrun effect if the risk contributes to a delay that also creates more overhead costs for project management staff. The monetized delay impact is calculated in the model by individually setting each risk to zero and recording the reduction in total project costs at the expected value in the model. Of particular interest in this figure is risk TRA 3 - Traffic Risk - Closure of 2 Lanes. This risk is a cost threat with a schedule opportunity. This is a risk of going to a two lane closure, which results in additional costs for traffic management; however it may reduce the construction schedule as closing two lanes may facilitate manhole work.

Figure 3 illustrates actual modeled delay to the project end date for each of the top 10 risk factors. This chart identifies the risks that are most likely to delay the whole project. These risks can be targeted for risk response mitigation strategies when trying to reduce the project schedule.

Figure 3: Top Schedule Risk Factors Tornado Chart - Longfellow Bridge Early Action (Phase 1)



2.1.2 Risk-Based Cost Estimate

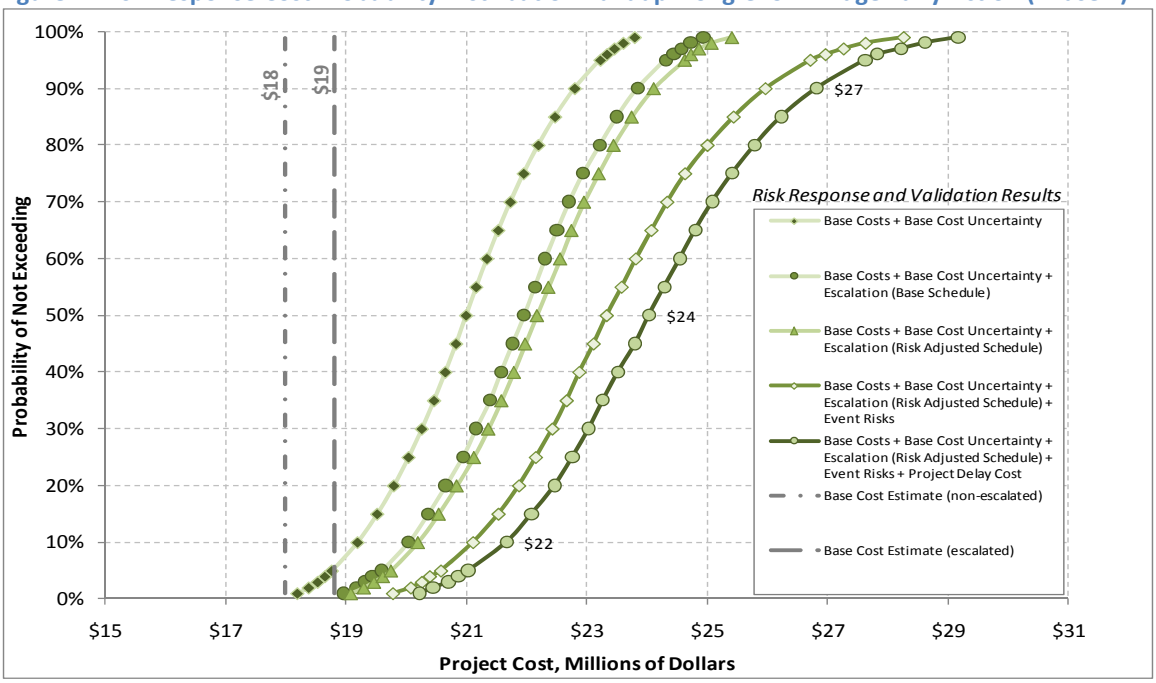
The risk-based cost estimate accounts for a variety of elements, which can be summarized as follows:

1. **The Base Cost** – the starting cost estimate for the analysis;
2. **Uncertainty Of The Base Cost** – a range of likely values around the base costs representing variability in the units and prices of inputs in the base cost estimate;
3. **Cost Escalation**– Escalation of construction input prices over the construction time period adjusted for the risk based schedule;
4. **Event Risks** – the addition of cost event risks to the overall costs; and

5. **Cost of Delay** – any delay to the schedule will increase the length of time staff and workers must remain on the project increasing the overall cost.

Each of the additional elements to the base cost contributes to the overall project cost differently and their impacts depend upon the assumed project cost, schedule, and escalation rates. With risk management involved, the buildup of costs from these elements is displayed in the following figure. In particular, the difference between the $18 million base cost and the first green curve is explained by the cost for mitigation of several schedule risks at $3.0 million over the estimated starting cost. The escalated base cost represents an additional cost of $1.0 million and this estimate increases to $3.0 million when uncertainty is included. Project cost with base uncertainties and escalation is about $22.2 million including a schedule uncertainty cost of $0.2 million. Finally, project cost risks and schedule risks will add $1.1 million and $0.7 million to the final estimate respectively.

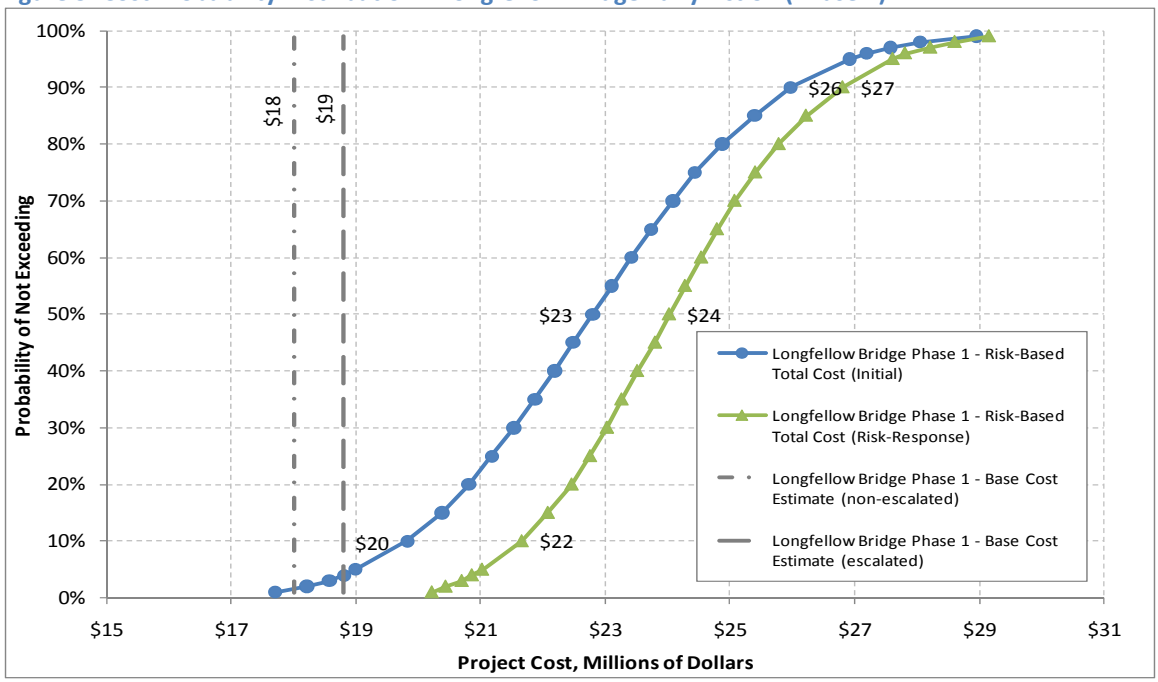
Figure 4: Risk Response Cost Probability Distribution Buildup- Longfellow Bridge Early Action (Phase 1)



The risk based cost estimate shows the cumulative probability distribution of the overall project cost (Figure 5). Each point on the distribution curve can be interpreted as the likelihood of completing the construction at or below the corresponding cost level. As shown in the figure, there is a high certainty (90 percent likelihood) that the total cost for the Longfellow Bridge Phase 1 project will not exceed $26 million before any risk response actions are taken. There is less than 5 percent likelihood that the project will be completed under the non-escalated base cost estimate of $18 million. With the risk response actions the median project costs are expected to increase slightly to $24 million from $23 million due to the cost of mitigating the schedule risks. This increase is due to the mitigation costs for risks UTL1 and UTL2 which total $3 million. Further investigation must be performed to determine if these risk response strategies will be worth undertaking, as they add to the overall cost of this project;

however these strategies may mitigate delays to the Longfellow Bridge Phase 2 contract which would result in less uncertainty and less risk in that contract with associated cost reductions.

Figure 5: Cost Probability Distribution – Longfellow Bridge Early Action (Phase 1)



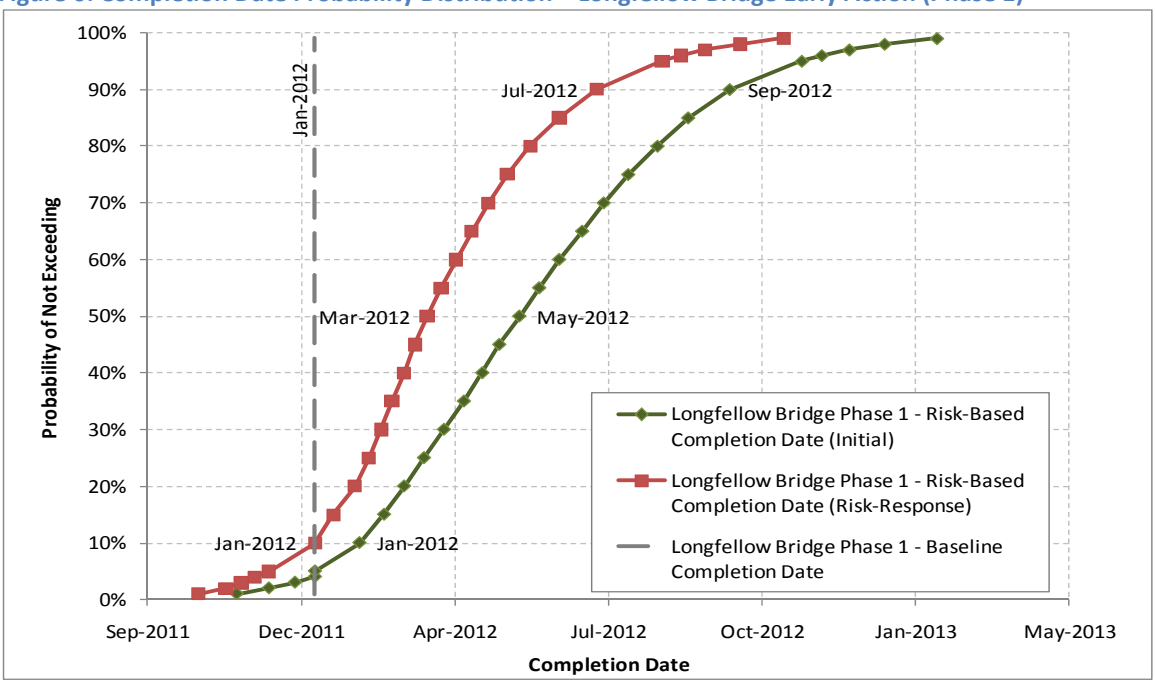
2.1.3 Risk-Based Schedule Estimate

The distribution of the completion date for the Longfellow Bridge Phase 1 is shown in Figure 6. In the initial analysis there is only a five percent likelihood that Phase 1 will be completed by the projected end date in January 2012. With risk response actions the likelihood of meeting this projected end date increases to 10 percent. There is a 90 percent chance that this project will be completed by September 2012. Risk Response actions can improve this to a 90 percent chance that the project is done by July 2012. Risk event delays to the project can impact the schedule during construction or prior to construction. Table 5 details the probability distributions for these specific areas. The risks impacting the start of construction are: ENV2 Conservation Commission Requirements, EXT2 Procurement Delays, and ENV1 Coast Guard Requirements.

Table 5: Schedule Delay Impacts – Longfellow Bridge Phase 1

Probability of Not Exceeding	Start of Construction - Risk-Based Delay (Initial)	Start of Construction - Risk-Based Delay (Risk-Response)	Risk-Based Delay to Construction Duration (Initial)	Risk-Based Delay to Construction Duration (Risk-Response)
10%	0.0 months	0.0 months	0.0 months	-0.9 months
50%	1.0 months	0.9 months	2.8 months	1.4 months
90%	4.5 months	4.1 months	6.6 months	3.5 months

Figure 6: Completion Date Probability Distribution – Longfellow Bridge Early Action (Phase 1)



2.9 Longfellow Bridge Phase 2 Cost and Schedule Risk Analysis Results

This section contains the results of the cost and schedule risk analysis for the Longfellow Bridge Phase 2 Project. The results include the key cost and schedule event risks as defined by the panelists during the April 8, 2010 workshop; the probability distribution of total project cost; and the probability distribution of project completion under the baseline (non-optimized) scenario. Refinements to the project inputs were made at the April 27, 2010 workshop. Further refinements to the inputs were made in the September 21 and 22, 2010 workshop as no further update of the design is available.

2.9.1 Key Project Risk Factors

Key project risk factors are potential events that will impact the cost or schedule of the Longfellow Bridge Phase 2 Project. These events are characterized by a probability of occurrence and potential range of impact if they occur. Figure 42 and Figure 43 illustrate the top cost and schedule impacts of risk events as well as the critical path schedule risk impacts at their expected value. In each chart, the initial assessment is shown for the top ten risks. Figure 42 shows the expected value cost impact of each individual event risk. The overall cost impact is composed of three parts: an event risk cost component, the escalation cost effect if the risk contributes to a delay, and the cost overrun effect if the risk contributes to a delay that also creates more overhead costs for project management staff. The monetized delay impact is calculated in the model by individually setting each risk to zero and recording the reduction in total project costs at the expected value in the model.

Figure 7: Combined Cost and Schedule Tornado Chart – Longfellow Bridge Phase 2

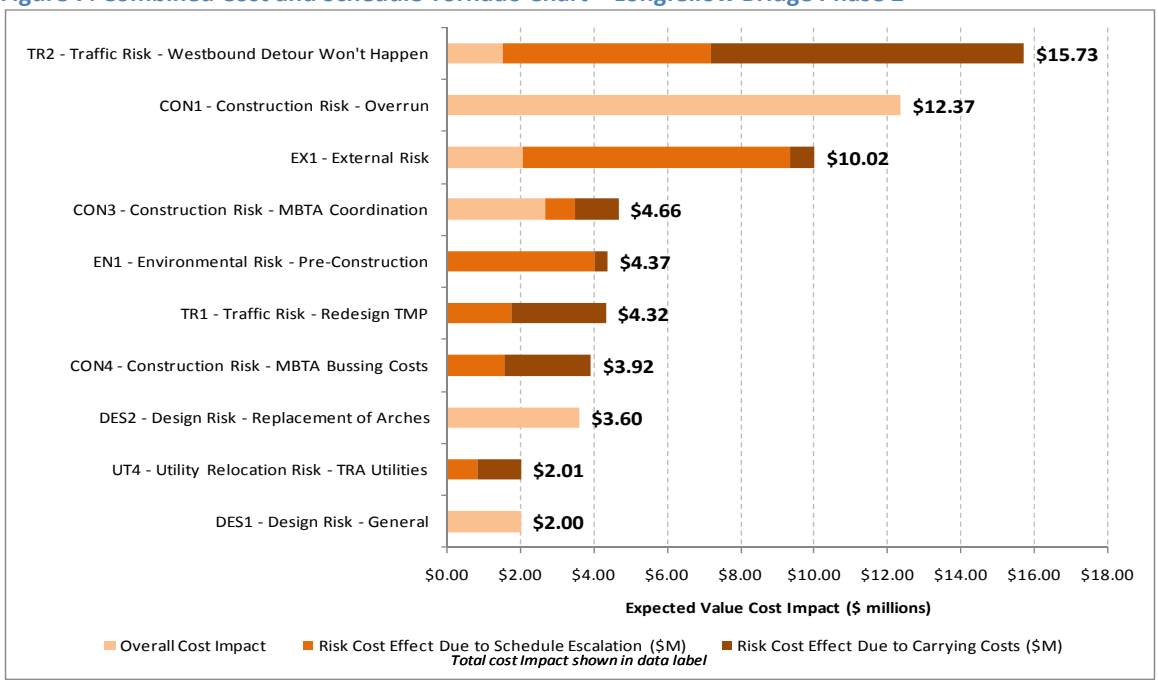
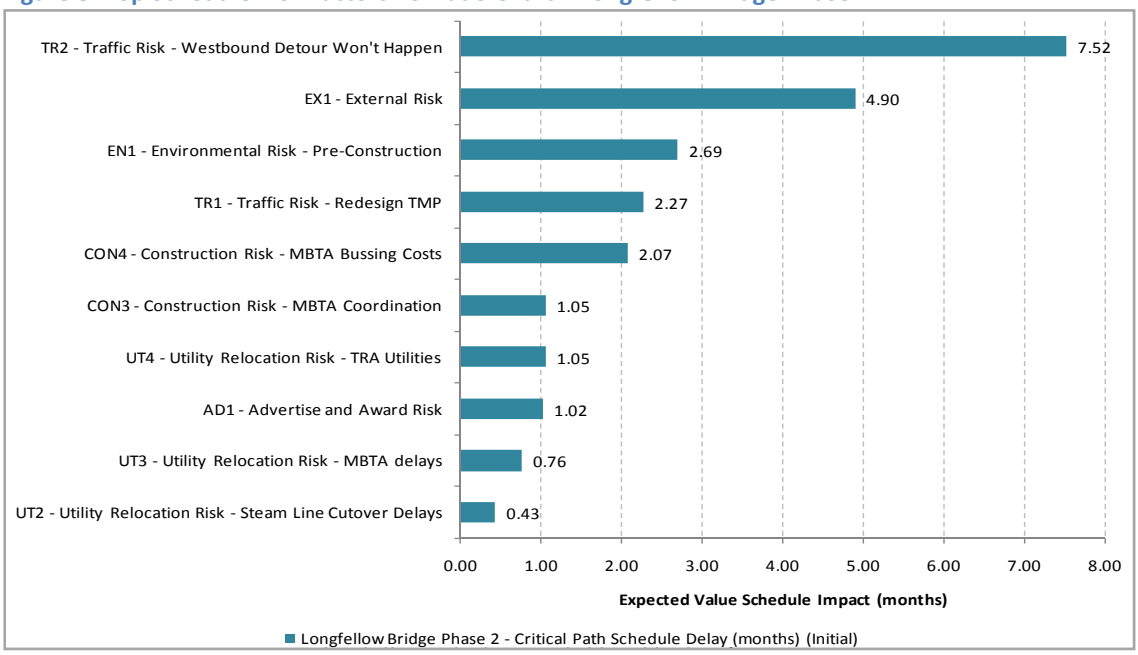


Figure 43 illustrates the impact of schedule risks as modeled in the analysis. This chart identifies the risks that are most likely to delay the overall project. These risks can be targeted for risk response mitigation strategies when trying to reduce the project schedule.

Figure 8: Top Schedule Risk Factors Tornado Chart – Longfellow Bridge Phase 2



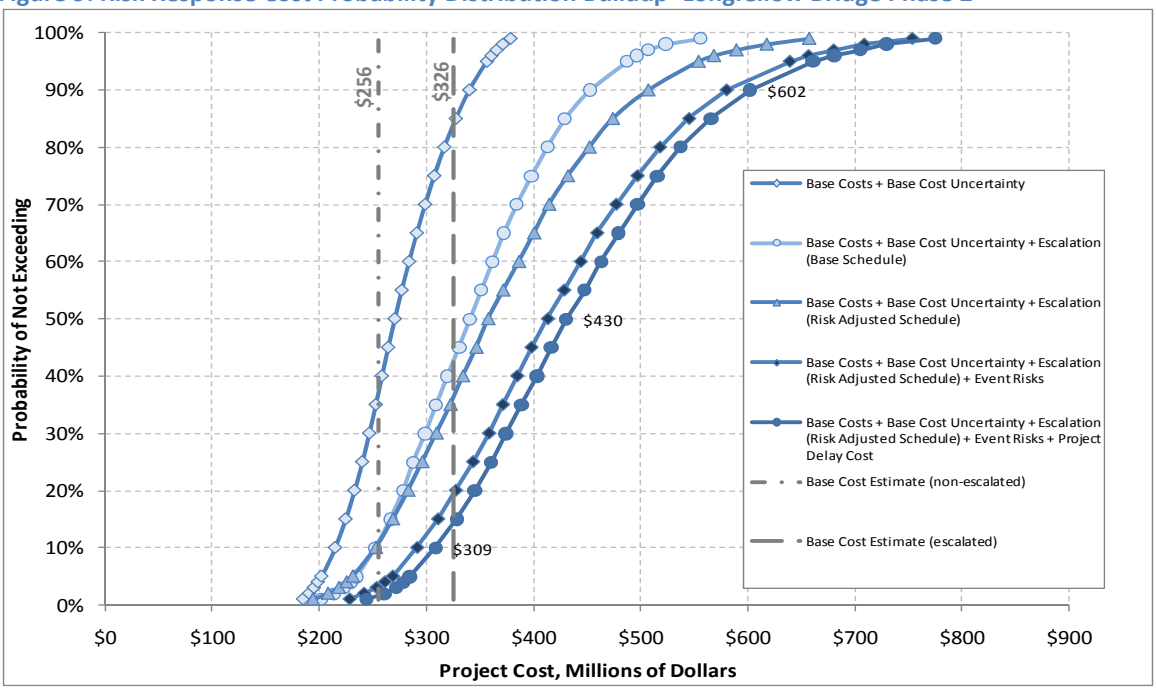
2.9.2 Risk-Based Cost Estimate

The risk-based cost estimate accounts for a variety of elements, which can be summarized as follows:

1. **The Base Cost** – the starting cost estimate for the analysis;
2. **Uncertainty Of The Base Cost** – a range of likely values around the base costs representing variability in the units and prices of inputs in the base cost estimate;
3. **Cost Escalation**– Escalation of construction input prices over the construction time period adjusted for the risk based schedule;
4. **Event Risks** – the addition of cost event risks to the overall costs; and
5. **Cost of Delay –** any delay to the schedule will increase the length of time staff and workers must remain on the project increasing the overall cost.

Each of the elements in additional to the base cost contribute to the overall project cost differently and their impacts depend upon the assumed project cost, schedule, and escalation rates. With risk management involved, the buildup of costs from these elements is displayed in the following figure. In particular, uncertainty of the base cost adds $14.8 million to the estimated starting cost. The escalated base cost adds $70.3 million to the base costs and this estimate increases to $85.0 million with uncertainty. Together with schedule uncertainty of $17 million, project cost with base uncertainties and escalation totals about $357.6 million. Finally, project cost risks and schedule risks will add $55.6 million and $17.3 million to the final estimate respectively.

Figure 9: Risk Response Cost Probability Distribution Buildup- Longfellow Bridge Phase 2



The risk based cost estimate shows the cumulative probability distribution of the overall project cost (Figure 45). Each point on the distribution can be interpreted as the likelihood of completing the construction at or below the corresponding cost level. As shown in the figure, there is a high certainty (90 percent likelihood) that the total cost for the Longfellow Bridge Phase 2 project will not exceed $602 million before any risk response actions are taken. There is less than 15 percent likelihood that the

project will be completed under the escalated base cost estimate of $326 million. The median project cost is expected to be $430 million.

2.9.3 Risk-Based Schedule Estimate

The distribution of the completion date for the Longfellow Bridge Phase 2 is shown in Figure 46. In the initial analysis there is less than a one percent likelihood that the Longfellow Bridge Phase 2 construction will be completed by the projected end date in September 2017. There is a 90 percent chance that this project will be completed by January 2021. Risk event delays to the project can impact the schedule during construction or prior to construction. Table 16 details the probability distributions for these specific areas. The risks impacting the start of construction are: DES3 Delay in Final Design NTP, AD1 Advertise and Award, EX1 External Risk and EN1 Preconstruction Environmental Permitting.

Table 6: Schedule Delay Impacts – Longfellow Bridge Phase 2

Probability of Not Exceeding	Start of Construction - Risk-Based Delay (Initial)	Risk-Based Delay to Construction Duration (Initial)
10%	0.0 months	4.8 months
50%	7.9 months	14.9 months
90%	18.2 months	27.4 months

Figure 10: Cost Probability Distribution – Longfellow Bridge Phase 2

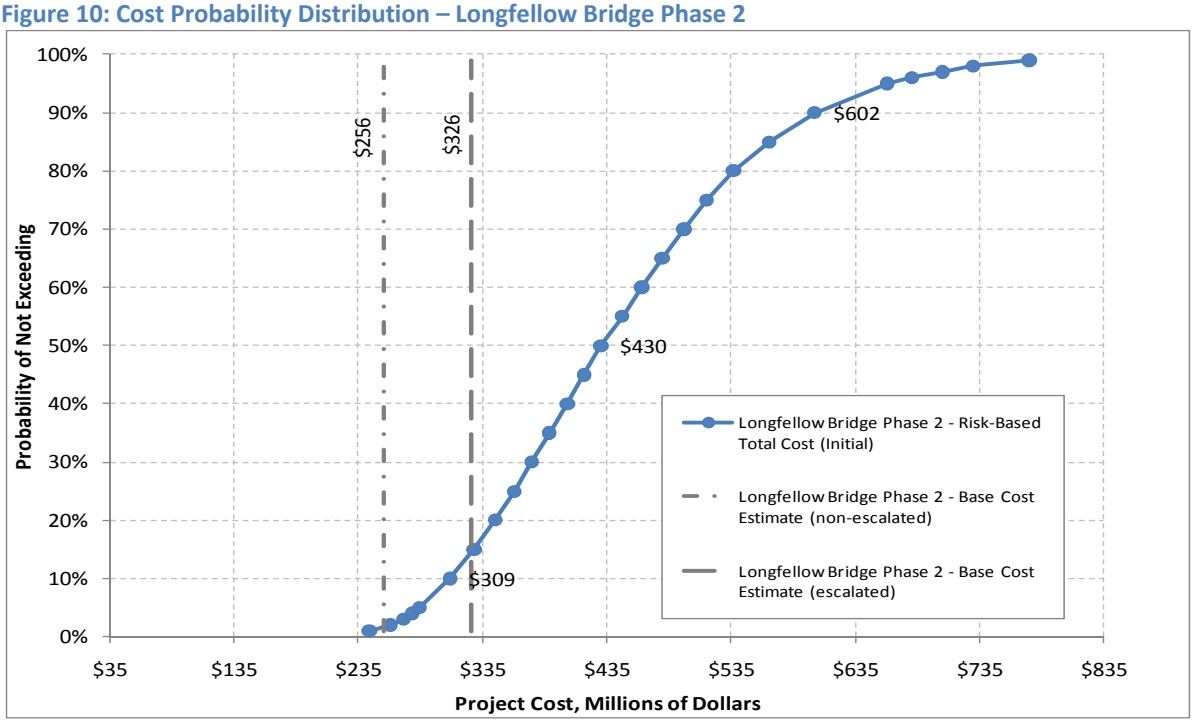
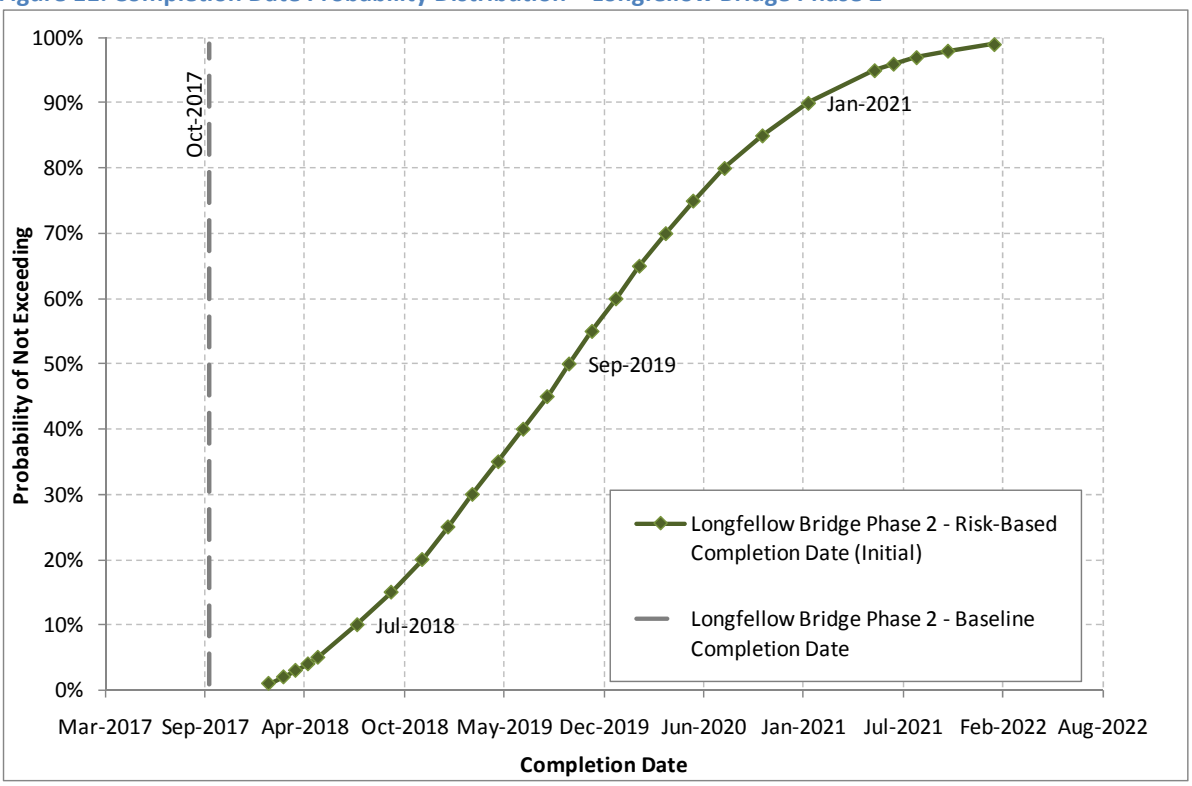


Figure 11: Completion Date Probability Distribution – Longfellow Bridge Phase 2



3 Optimized Sequencing Model for Bridge Rehabilitation

3.1 Sequencing Updates

Considering the September 2010 updates to the risk analysis and project cost and schedule outputs, an update to the optimal sequencing is required. Beyond the updates to the sequencing model inputs, in terms of project cost and schedule, another constraint was placed on the sequence model. This constraint does not allow the construction of the Anderson Memorial Bridge to overlap with the construction of the River Street and Western Avenue Bridges. Given the proximity of the projects and potential for significant traffic negative traffic impacts by working on all three bridges simultaneously, in the September 2010 update workshop, the decision was made to not allow for an overlap. Additionally, the River Street and Western Avenue Bridges were set to run in parallel for construction. In this update, two scenarios were considered:

- **Scenario 1** – the River Street and Western Avenue Bridges are constructed first and the Anderson Memorial Bridge construction starts after the River and Western Avenue Construction are complete; and
- **Scenario 2** – The Anderson Memorial Bridge is constructed first and the River Street and Western Avenue Bridge construction starts after the Anderson Memorial Bridge construction is complete.

Given the sequencing definition and constraints, one of these scenarios will be part of the optimal solution. To reiterate from previous analyses, the objectives of the optimal sequencing model are to:

- Minimize traffic disruption costs due to lane closures during construction;
- Minimize total project costs, including:
    - Minimizing cost premiums due to labor and material shortages when multiple projects overlap during construction;
    - Minimizing project escalation costs due to pushing projects further into the future; and
- Complete all projects by the end of 2016 (however this is not set as a hard constraint, given that the risk profile of some projects cause them to end outside of the 2016 window).

The model achieves these objectives by changing the start date for construction for each project (note not all projects have a flexible start date). Ultimately, this analysis determines the optimal starting time for each project. The optimal sequencing follows the same approach as in the previous analysis. For full information on the sequencing approach, please see the June 21, 2010 memorandum entitled "Accelerated Bridge Program, 10 Bridges and Roadway Projects, Cost Analysis and Sequencing Report" by the PARM team, which presented the initial results.

3.2 Sequencing Model Inputs

The key inputs to the sequencing model come from the cost risk analysis and are displayed in Table 18 and Table 19. These inputs from the cost risk analysis model are representative of the 50th percentile of the cost risk results. The inputs include:

- The base schedule and duration of construction;
- The range of potential construction start dates for the project (note not all projects have a flexible start date);
- The reduction in lanes during construction;
- The 50th percentile of risk adjusted project costs;
- The 50th percentile of risk adjusted delay to the start of construction; and
- The 50th percentile of risk adjusted construction duration.

As noted above, not all projects have a flexible start date. In the sequencing model, these dates are taken as a given. There are four of the analyzed projects that have the flexibility to shift the starting date to improve the sequencing order of the projects. These projects list their Base Early Start and Base Late Start dates as different values from the Base Start Date. The sequencing model will use the flexibility of these projects to seek the optimal project schedule. These four projects are:

1. Anderson Memorial Bridge;
2. Western Avenue Bridge;
3. River Street Bridge; and
4. Massachusetts Turnpike Viaduct.

The remaining projects have no real flexibility in when the start of work can begin. These projects are all listed with the same Base Early Start and Base Late Start dates and do not vary throughout the results of the sequencing model.

Table 7: Sequencing Inputs - Schedule

Project Name	Base Activity Durations	Lanes Closed During Construction	Total Lanes	Base Start Date	Base Early Start	Base Late Start
Longfellow Bridge Phase 1	**19.0**	2	4	Jun-10	Jun-10	Jul-10
Anderson Memorial Bridge	**20.0**	2	4	Aug-11	Aug-11	Mar-15
Western Avenue Bridge	**24.0**	1	3	Sep-11	Aug-11	Sep-13
River Street Bridge	**24.0**	1	3	Sep-11	Aug-11	Sep-13
Craigie Drawbridge	**9.0**	3	5	Nov-10	Nov-10	Nov-10
BU Bridge	**30.0**	2	4	Jun-09	Jun-09	Jun-09
Magazine Beach Pedestrian Bridge	**18.0**	0	4	Apr-10	Mar-10	Apr-10
Mass Turnpike Viaduct	**24.0**	2	4	Mar-14	Mar-12	Mar-16
Longfellow Bridge Phase 2	**62.0**	2	4	Aug-12	Apr-12	Apr-12
Craigie Roadway	**18.0**	0	5	Feb-10	Feb-10	Feb-10

Table 8: Sequencing Inputs - Cost

Project Name	Risk Adjusted Inputs for Pre-Risk Response -- 50th Percentile			Risk Adjusted Inputs for Post Risk Response -- 50th Percentile		
	Risk Adjusted Cost	Start Risk Delay (days)	Duration Risk (months)	Risk Adjusted Cost	Start Risk Delay (days)	Duration Risk (months)
Longfellow Bridge Phase 1	$21.6	1.0	2.8	$22.8	0.9	1.4
Anderson Memorial Bridge	$30.5	3.1	4.0	$28.8	1.2	1.0
Western Avenue Bridge	$35.1	5.0	9.6	$29.9	1.6	3.4
River Street Bridge	$40.7	5.1	13.9	$40.3	3.7	13.6
Craigie Drawbridge	$38.8	0.0	0.0	$38.8	0.0	0.0
BU Bridge	$16.4	0.0	0.0	$16.4	0.0	0.0
Magazine Beach Pedestrian Bridge	$4.1	0.0	0.0	$4.1	0.0	0.0
Mass Turnpike Viaduct	$8.8	0.0	0.0	$8.8	0.0	0.0
Longfellow Bridge Phase 2	$330.2	7.9	14.9	$330.2	7.9	14.9
Craigie Roadway	$5.0	0.0	0.0	$5.0	0.0	0.0

3.3 Sequencing Results – Scenario 1

Based on the results of the optimal sequencing analysis, Scenario 1 – the River Street Bridge and Western Avenue Bridge construction completing before the Anderson Memorial Bridge construction begins, is the optimal sequence. Scenario 1 was the solution arrived at by minimizing the costs discussed at the beginning of this chapter. A comparison of the sequencing results between the two scenarios is provided at the end of this chapter.

Figure 52 illustrates the non optimized project sequencing at the 50th percentile risk-adjusted project schedule and durations. This serves as the base schedule for the sequencing results comparison. Figure 53 illustrates the optimized project sequencing without risk response strategies for the 50th percentile cost and schedule inputs. The key difference in this schedule is the adjustment to the Massachusetts Turnpike Viaduct construction period suggesting that start of construction for this project should be delayed by two years. These schedule adjustments are to minimize overlapping of projects, thereby minimizing cost premiums and traffic disruption costs.

Figure 12: Non-Optimized Project Sequencing (50th Percentile Risk) – Scenario 1

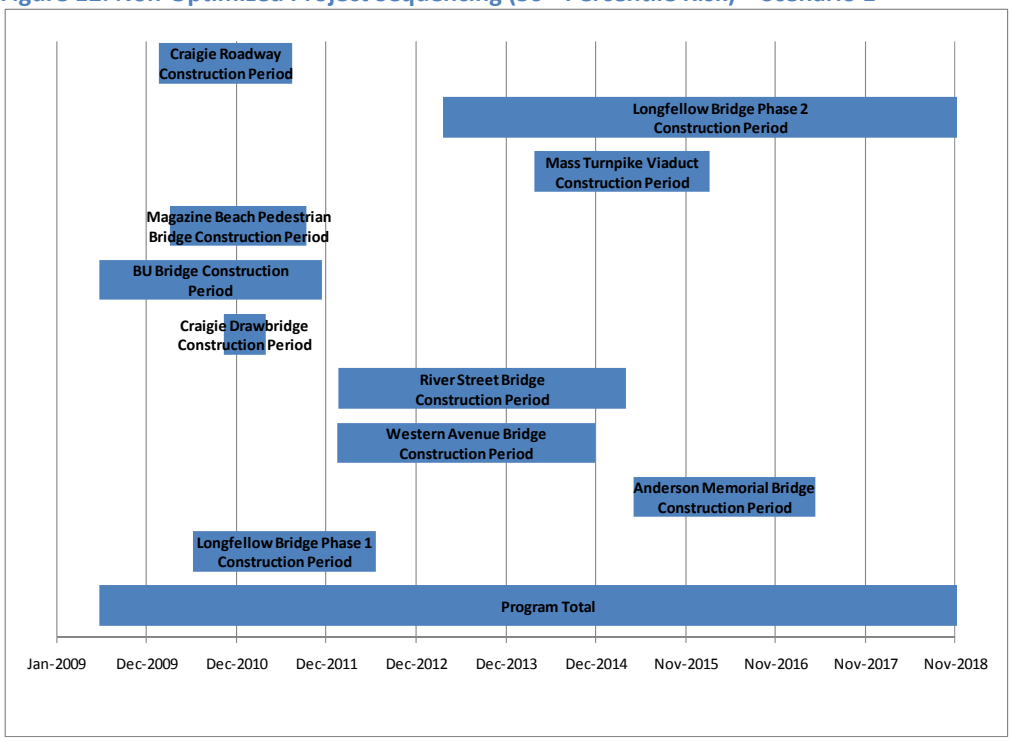
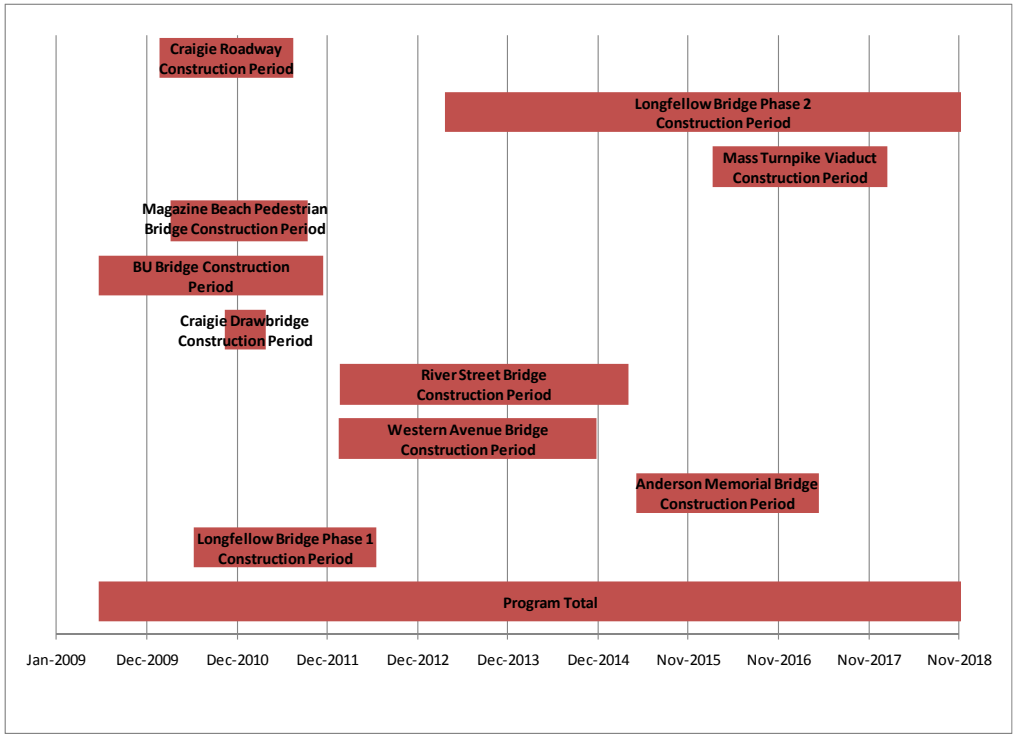
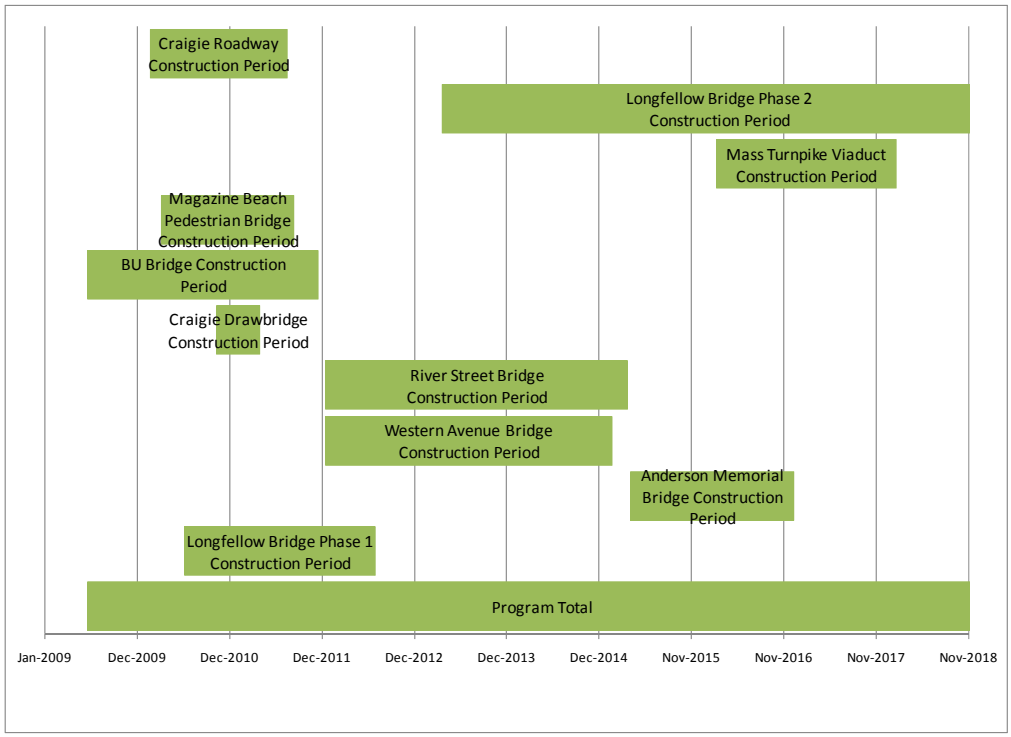


Figure 13: Optimal Project Sequencing without Risk Response (50th Percentile Risk) – Scenario 1



The optimized schedule with risk response is illustrated in Figure 54. The key to this schedule is the reduction in construction duration for the projects that have addressed risk response alternatives. The projects with significantly shorter construction duration include the Anderson Memorial Bridge Avenue and Magazine Beach Pedestrian Bridge. These shorter duration projects allow for the overlap cost in the projects to be further minimized, with minor adjustments made to the construction start dates.

Figure 14: Optimal Project Sequencing with Risk Response (50th Percentile Risk) – Scenario 1



Re-arranging the sequence of construction demonstrates improvements in total project costs. Table 20 summarizes the overall project costs before and after optimization. Under the non-optimized baseline costs, the total cost for all bridges is $682.1 million, which is composed of $536.2 million in project costs with risk, $134.5 million in escalation costs, and $11.3 million in project overlap cost premium. With optimization prior to any risk response actions there is a cost avoidance of $4.6 million in traffic disruption and construction. This cost avoidance is a combination of reducing the incremental costs stemming from the project overlap of $2.0 million and traffic disruption costs of $3.6 million.

When risk response strategies are pursued, the cost avoidance over the baseline costs increase to a net savings of $17.2 million with cost avoidance. These savings are composed of non-escalated project costs ($6.2 million), project overlap costs ($1.8 million), traffic disruption costs ($6.7 million), and escalation reduction ($2.5 million). The cost avoidance is driven by the shortening of project schedules, and reduction in the likelihood that project construction periods overlap and resulting in over and above cost premiums and traffic disruption costs.

Table 9: Summary Sequencing Results in Millions (2010 $M)

Cost Categories	Baseline Sequence – Pre-Risk Response	Optimized Sequence - Pre-Risk Response	Change over Baseline (Cost Avoidance)	Optimized Sequence - Post-Risk Response	Change over Baseline (Cost Avoidance)
Total Cost (All Bridges)	**$682.1**	**$681.1**	**-$1.0**	**$671.6**	**-$10.5**
Non-Escalated Cost	$536.2	$536.2	$0.0	$530.0	-$6.2
Cost of Escalation	$134.5	$135.5	$1.0	$132.1	-$2.5
Project Overlap Costs	$11.3	$9.4	-$2.0	$9.5	-$1.8
Traffic Disruption Costs	**$143.9**	**$140.3**	**-$3.6**	**$137.1**	**-$6.7**
Total Costs (Traffic and Construction)	**$826.0**	**$821.4**	**-$4.6**	**$808.7**	**-$17.2**

The optimization does not impact the project costs of each product equally. Table 21 compares the baseline total cost to the optimized total costs. This table focuses on the total project costs without the traffic disruption user costs. This table enables the projects responsible for the cost avoidance to be identified. By altering the start of construction at the Anderson Memorial Bridge, River Street Bridge, and Massachusetts Turnpike Viaduct by several months the optimized costs of these projects decreased by $3.0 million in total costs (pre-risk response costs). Delaying the construction period of the Massachusetts Turnpike Viaduct also reduces the expected project overlap costs.

Table 10: Sequencing Results by Project ($M)

Bridge Name	Baseline Total Cost	Optimization Total Cost - Pre-Risk Response	Change over Baseline Pre-Risk Response	Optimization Total Cost - Post-Risk Response	Change over Baseline Post-Risk Response
Longfellow Bridge Phase 1	$25.6	$25.6	$0.0	$26.9	$1.3
Anderson Memorial Bridge	$43.8	$41.8	-$2.0	$39.3	-$4.5
Western Avenue Bridge	$43.9	$41.9	-$2.0	$35.5	-$8.5
River Street Bridge	$48.8	$48.8	$0.0	$48.3	-$0.5
Craigie Drawbridge	$48.2	$48.2	$0.0	$48.2	$0.0
BU Bridge	$17.0	$17.0	$0.0	$17.0	$0.0
Magazine Beach Pedestrian Bridge	$4.4	$4.4	$0.0	$4.4	$0.0
Mass Turnpike Viaduct	$11.7	$12.7	$1.0	$12.7	$1.0
Longfellow Bridge Phase 2	$439.4	$439.4	$0.0	$439.4	$0.0
Craigie Roadway	$5.2	$5.2	$0.0	$5.2	$0.0
Total	**$688.0**	**$685.0**	**-$3.0**	**$676.9**	**-$11.2**

Note: Costs are based on the 50th percentile risk analysis results as an input to the sequencing model, and include escalation costs and project overlap cost premiums due to labor and material shortages.

After risk response strategies are pursued, the optimized total cost includes further reduction in project cost for the Anderson Memorial Bridge, River Street Bridge, and Western Avenue Bridge. This reduction

in cost is driven primarily by the schedule duration reductions due to risk response strategies. The schedule duration reductions create an additional cost avoidance of $8.2 million over the optimized total cost and a total of $11.2 million in cost avoidance from the baseline sequence costs.

3.4 Comparison to Scenario 2

Based on the results of the optimal sequencing analysis, Scenario 2 – which includes the Anderson Memorial Bridge construction completing before the River Street and Western Avenue Bridges construction starting is not the optimal sequence. Scenario 2 has higher costs associated with it than constructing the River Street Bridge and Western Avenue Bridge before the Anderson Memorial Bridge. Specifically, scenario 2 has higher project overlap costs as well as higher traffic disruption costs due to more lanes being closed simultaneously. Escalation costs are lower because the River Street and Western Avenue Bridges have a higher combined cost than the Anderson Memorial Bridge, therefore moving them sooner in the sequencing of projects results in a lower overall escalation of costs for the program. These findings are true in both the pre- and post- risk response results. These results are presented in Table 22 and Table 23.

Table 11: Comparison between Scenario 1 and 2 – Pre-Response

Cost Categories	Optimized Sequence - Pre-Risk Response		Difference
	Scenario 1 - River and Western First	Scenario 2 - Anderson First	
Total Cost (All Bridges)	**$681.10**	**$683.52**	**$2.43**
Non-Escalated Cost	$536.21	$536.21	$0.00
Cost of Escalation	$135.52	$133.74	($1.78)
Project Overlap Costs	$9.36	$13.57	$4.21
Traffic Disruption Costs	**$140.29**	**$147.81**	**$7.52**
Total Costs (Traffic and Construction)	**$821.38**	**$831.33**	**$9.95**

Table 12: Comparison between Scenario 1 and 2 – Post-Response

Cost Categories	Optimized Sequence - Post-Risk Response		Difference
	Scenario 1 - River and Western First	Scenario 2 - Anderson First	
Total Cost (All Bridges)	**$671.57**	**$674.10**	**$2.53**
Non-Escalated Cost	$530.03	$530.03	$0.00
Cost of Escalation	$132.05	$130.51	($1.54)
Project Overlap Costs	$9.49	$13.56	$4.07
Traffic Disruption Costs	**$137.13**	**$146.00**	**$8.86**
Total Costs (Traffic and Construction)	**$808.71**	**$820.09**	**$11.39**

4 Summary of Risk Analysis and Optimization

A cost and schedule risk analysis was conducted for the ten bridges and roadway projects as part of the Accelerated Bridge Program for the MassDOT. Accounting for event risks associated with these projects, risk-adjusted costs and schedules were developed by the PARM team to reflect the mostly likely outcomes at the 50th percentile and those with a high degree of confidence at the 90th percentile. As part of the risk management process, regular updates to this analysis take place, as project costs, schedules and risks are continually refined throughout the project lifecycle. An updated risk workshop was held on September 21 and 22, 2010 to revisit the risks for the Longfellow Bridge Phase 2, the Anderson Memorial Bridge, the River Street Bridge and the Western Avenue Bridge Projects. During this session, the base cost and schedule inputs were updated, and key project risk factors were revisited and updated by the workshop participants based on the current risk profiles of the projects. Note that the risk response strategies were not revisited during this workshop. Additionally, the base cost and schedule inputs have been updated for many of the other projects based on the September 2010 MassDOT ABP Quarterly Report. With the updated risk analysis results, the optimal sequencing analysis was updated to determine the best order for the projects to be constructed. This updated report presents the results from this latest round of analysis.

4.1 Summary of Risk Analysis Results

The risk-adjusted cost for each ABP project is reported in Table 24. These represent the latest cost results for each of the 10 projects analyzed. In cases where risk response strategies were provided, the results reflect the inclusion of these strategies. Note these results represent the individual project costs, prior to the sequencing analysis, i.e. if each project was built alone, without other projects.

Table 13: Risk-Adjusted Project Cost Summary in Millions (2010 $)

Bridge Name	10th	50th	90th
Longfellow Bridge Phase 1*	$21.7	$24.0	$26.8
Anderson Memorial Bridge*	$23.3	$33.7	$43.5
Western Avenue Bridge*	$27.6	$35.0	$52.0
River Street Bridge*	$33.4	$45.9	$63.6
Craigie Drawbridge	$37.8	$41.9	$51.5
BU Bridge	$14.8	$16.5	$18.2
Magazine Beach Pedestrian Bridge	$3.8	$4.1	$4.6
Mass Turnpike Viaduct	$7.7	$11.1	$16.2
Longfellow Bridge Phase 2	$308.6	$430.4	$602.1
Craigie Roadway	$5.0	$5.0	$5.0
Total	**$483.8**	**$647.7**	**$883.7**

*Note: * With Risk Response, for non-starred projects risk response workshops have not yet been conducted*

Table 25 presents the risk analysis results for completion dates for each of these projects. In cases where risk response strategies were provided, the results reflect the inclusion of these strategies. Note these results represent the individual project costs, prior to the sequencing analysis, i.e. if each project was built alone, without other projects.

Table 14: Risk-Adjusted Project Schedule Summary (months)

Bridge Name	10th	50th	90th
Longfellow Bridge Phase 1*	Jan-12	Mar-12	Jul-12
Anderson Memorial Bridge*	Apr-13	Jul-13	Mar-14
Western Avenue Bridge*	Oct-13	Mar-14	May-15
River Street Bridge*	Mar-14	Feb-15	Apr-16
Craigie Drawbridge	Aug-11	Aug-11	Sep-12
BU Bridge	Dec-11	Jan-12	Mar-12
Magazine Beach Pedestrian Bridge	Oct-11	Oct-11	Mar-12
Mass Turnpike Viaduct	Mar-16	Apr-16	Jun-16
Longfellow Bridge Phase 2	Jul-18	Sep-19	Jan-21
Craigie Roadway	Aug-11	Aug-11	Oct-11

** With Risk Response, for non-starred projects risk response workshops have not yet been conducted*

4.2 Summary of Optimal Sequencing Results

The optimal sequencing analysis has been updated to reflect the revised cost and schedule inputs from the risk analysis. Additionally, two scenarios were considered:

- Scenario 1 – The River Street and Western Avenue Bridges are constructed first and Anderson Memorial Bridge construction starts after the River Street and Western Avenue Bridges are complete, and
- Scenario 2- The Anderson Memorial Bridge is constructed first and the River Street and Western Avenue Bridges start after the Anderson Memorial Bridge construction is complete.

Table 26 presents the results for Scenario 1, which turned out to be the optimal sequence.

Table 15: Sequencing Results Summary – Scenario 1

Cost Categories	Baseline Sequence – Pre-Risk Response	Optimized Sequence - Pre-Risk Response	Change over Baseline (Cost Avoidance)	Optimized Sequence - Post-Risk Response	Change over Baseline (Cost Avoidance)
Total Cost (All Bridges)	**$682.1**	**$681.1**	**-$1.0**	**$671.6**	**-$10.5**
Non-Escalated Cost	$536.2	$536.2	$0.0	$530.0	-$6.2
Cost of Escalation	$134.5	$135.5	$1.0	$132.1	-$2.5
Project Overlap Costs	$11.3	$9.4	-$2.0	$9.5	-$1.8
Traffic Disruption Costs	**$143.9**	**$140.3**	**-$3.6**	**$137.1**	**-$6.7**
Total Costs (Traffic and Construction)	**$826.0**	**$821.4**	**-$4.6**	**$808.7**	**-$17.2**

Overall the sequencing reduces project costs by $1.0 million in the pre-response results and $10.5 million in the post-response results. This is due to a savings in project overlap, and in the case of the post-response results a savings in escalation costs. Additionally, there is a savings of $3.6 million and $6.7 million in traffic disruption costs, due to the optimized sequence, in the pre- and post-response results respectively.

When re-sequencing the work to put the Anderson Memorial Bridge ahead of the River Street and Western Avenue Bridges, there is an additional cost of $9.9 million related to project overlaps and traffic disruption costs for the pre-response results. This number increases to $11.4 million in the post-response. For reference, these results are presented in **Section 3.4**.

4.3 Next Steps

Initial Risk Assessment and project optimization have been conducted on ten bridge projects. Of these projects, four have gone through the risk response planning to address. This leaves significant work to still be done on the assessment of the ABP. It is important to continue to address the scalability of this analysis with the intention of refining the analysis over time, by adding additional bridge projects as well as examining each project in further detail.

The next steps to continue to refine the initial risk assessments are to conduct risk response workshops for the Craigie Drawbridge, BU Bridge, Magazine Beach Pedestrian Bridge, Massachusetts Turnpike Viaduct, Longfellow Bridge Phase 2, and the Craigie Roadway. These new results will be added to this report for further understanding of cost and schedule risks and their impacts on the program sequencing. Following that, additional projects should be identified for risk analysis workshops and inclusion into the sequencing models. The sequencing model can then be updated based on the new inputs. Throughout these next steps, the ongoing work on each bridge will be tracked and so that the cost risk analysis and sequencing model are continuously refined.

The work to date shows a significant addition to expected cost from escalation. This result contradicts the observed condition over the past year or more that construction prices are in fact contracting, not escalating. This contradiction is being further evaluated and the results will be included in the next round of assessments.

Base prices are considerably higher than current market conditions indicate based on contracts awarded nationwide over the past 1-2 years. This outcome results from the way unit costs are given in the MassDOT procedures used to develop the Engineer's cost estimate. The impact of this difference will be included in the next round of assessments by examining unit costs from a contractor's perspective.